~~GAS SENSOR AND THE USE THEREOF~~

BACKGROUND OF THE INVENTION

The present invention is concerned with lambda probes for exhaust gas measurement and is particularly directed to a gas sensor ~~according to the preamble of claim 1~~ and to a method for the employment of a gas sensor according to the preamble of the independent method claim.

Lambda probes are utilized in the automotive field in order to monitor the ratio of fuel to air, so that the fuel introduced in the motor is completely converted without excess air entering into the combustion chamber. Given an air excess, atmospheric oxygen reacts with atmospheric nitrogen in the combustion heat [sic] to form nitrogen oxides, and the pollutant emission of the motor increases. Lack of air, in contrast, leads to incomplete fuel combustion and is therefore inefficient.

One criterion for the composition of the air/fuel mixture is what is referred to as the lambda value. ~~Given an~~ exactly correct ratio of fuel to ~~air, it~~ is exactly one. When too much oxygen is introduced into the motor for a given fuel quantity, then lambda value is greater than 1; "lean operation" of the motor is ~~referred to~~ in view of the fuel deficiency. Here, the excess oxygen leaves the combustion chamber, and the oxygen content in the exhaust gas is high, with a partial oxygen pressure that typically lies in the percent range. When, in contrast, too little oxygen is introduced for a given fuel quantity, lambda is less than 1; this is referred to as a "rich mixture". Under these conditions, the atmospheric oxygen is practically completely converted, so that the partial oxygen pressure in the exhaust gas is several orders of magnitude lower than given lean operation.

A known arrangement for measuring the partial oxygen pressure is disclosed by DE 42 03 522 C1. It is thereby proposed to provide an O_2 sensor arrangement on the basis of semiconducting metal oxides whose conductivity at elevated temperature is dependent on the partial oxygen pressure, and wherein the sensor arrangement comprises two individual metal oxide sensors that, in the intended range of measurement, exhibit a different dependency of the conductivity on the partial oxygen pressure but a largely identical temperature dependency of the conductivity that is largely brought into relief in the quotient of the measured

conductivity signals of the two sensors that are formed. The sensors can thereby be selected such that their characteristics, i.e. the dependency of their conductivity on the oxygen concentration, proceed oppositely, ~~whereby~~ so that linear characteristics derive over broad ranges in double logarithmic plotting but the usual characteristic minimum can also occur. An employment of the sensor for measuring exhaust gas is not mentioned.

DE 38 33 295 A1 discloses a sensor arrangement wherein two metal oxide resistors are provided and, for temperature compensation, a shunt resistor is allocated to the one metal oxide resistor. The publication is not concerned with the catalytic activation of gas sensors.

European Patent Application EP 91 116 715 discloses an exhaust gas sensor for regulating internal combustion engines wherein a sensor unit is provided as a combination of two sensor elements that are arranged on a common substrate, whereby the one sensor element carries a catalyst layer on it and is intended to measure the partial oxygen pressure after the exhaust gas has completely reacted, for example at the sensor electrode, and whereby the other sensor element, which carries no catalyst layer, simultaneously measures the partial oxygen pressure in the exhaust gas without the catalytic setting of stoichiometric conditions, and whereby the difference signal of the signal from the one sensor element and the other sensor element is a direct measure for the incompleteness of the combustion in the internal combustion engine. The sensor elements should be identical in structure with the exception of the catalyst layer on the sensor element, and the two sensor electrode pairs are to be connected opposite one another for acquiring the difference signal. The difference circuit, however, often produces only a low output signal that, accordingly, is sensitive to interference and the like. Moreover, the signal discontinuity at the point lambda equal to 1.0 is largely suppressed by the difference formation.

Summary of The Invention

A goal of the present invention is to create something new for commercial application and, particularly but not exclusively, to allow an especially precise and nonetheless fast measurement of the lambda value broad-band even given what is an unfavorable signal-to-noise ratio due to external interference.

The goal of the present invention is achieved by ~~the independent claims~~, ~~whose preferred embodiments are recited in the dependent claims~~.

Inventively, at least one sensor region at the gas sensor comprises pores into which a catalytically active substance is directly introduced as catalytic means. Since the exhaust gases proceed immediately onto the sensor region without having to previously pass through a separate catalyst layer, the sensor, on the one hand, responds especially quickly but, on the other hand, simultaneously allows an especially precise measurement since no diffusion-inhibiting layer is present over which an oxygen gradient that falsifies the measured value could build up.

Especially preferably, the gas sensor is manufactured with two identical sensor regions, for instance with a silk-screening process and strontium titanate layers, whereby traces of at least one platinum metal as catalytically active material are introduced into the thick-film pores of the one sensor region formed in this way.

The platinum metal can be dribbled onto the thick-film as a fluid containing platinum metal, subsequently penetrating into the pores by capillary action. After ~~drawing~~, the residue in the pores can be subjected to thermolysis. An essentially uniform activation of the sensor region over the entire layer thickness is thus achieved.

The invention also discloses a method for employing a gas sensor as lambda probe; the gas sensor comprises two resistive sensor regions that respond to at least one reactive exhaust gas constituent as well as a catalytic agent for converting the reactive exhaust gas constituent with higher catalytic activity at one sensor region. Both sensor regions discontinuously change their resistance in the region around $\lambda=1$. Due to the different catalytic activity, the two sensor signals, however, vary differently with λ: the resistance of a catalytically highly activated layer decreases monotonously toward the rich below $\lambda=1$ but hardly changes in the ~~lean. Given and at~~ most less activated layer, the situation is opposite; in the lean above $\lambda=1$, its film resistance increases noticeably with λ; however, it hardly changes in the rich. Inventively, the two different sensor signals are interpreted ~~such in parallel~~ that the overall signal change of the parallel evaluation signal in a first exhaust gas mixture range is dominated by changes of the first sensor signal and is dominated by changes

of the second sensor signal in a second exhaust gas mixture range. In particular, the exhaust gas mixture ranges can be a matter of the ranges above or, respectively, below $\lambda=1$.

The inventive parallel interpretation of the two sensor signals enables the desired, broadband measurement of lambda wherein it is not only the direction of the deviation from the ideal value $\lambda=1$ but also the size thereof that can be identified. At the same time, the signal boost is always still high enough even under unfavorable conditions that the transition from the rich to the lean can be dependably recognized under all conditions.

A preferred parallel interpretation is based on the employment of a logic circuit to which the two sensor signals are supplied independently of one another. The logic circuit determines on the basis of at least one of the two sensor signals whether the exhaust gas mixture is in the first or second exhaust gas mixture range and outputs an output signal in response to the identified exhaust gas mixture range that is respectively dominated by one of the two sensor signals.

The logic circuit can undertake a weighting of the two signal parts varying with λ, whereby respectively one of the weighting coefficients strives toward one for the lean and rich, and whereby both sensor signals are identically weighted around the point $\lambda=1$. This can be realized with "unsharp logic".

The logic circuit can also work as multiplexer whose input channel selected for the through-connection is dependent on whether the signal allowed to pass at the moment represents a high or low resistance value. Optionally, a signal can also be permanently connected for interpretation to a comparator that identifies the side of the discontinuity at which the resistance value lies. The signal to be applied to the multiplexer output can be selected in response to the comparator output. The parallel interpretation, accordingly, is comprised in the forwarding of the selected signal of both signals supplied in parallel to the multiplexer.

The sensor signals need not be directly supplied to the logic circuit but can be previously edited as needed, particularly amplified and/or digitalized. The separate signal processing of the sensor signals from both sensor regions is advantageous in order to allow an optimum matching of the gain, of the input impedance, etc., to the

respective sensor layer on the basis of separate processing of the sensor signals, this improving the signal-to-noise ratio. Optionally, a multiplexer can also be arranged preceding the signal conditioning circuit for cost reasons.

Alternatively, a simple electrical parallel circuiting of the sensor signals can ensue instead of the logic circuit. This is particularly meaningful when an economical lambda probe arrangement is desired and the values of resistance of both sensitive layers approximately correspond to one another.

Although the method is preferably implemented with a gas sensor of the present invention that is directly catalytically activated, i.e. whose sensor regions are provided with catalytically active substance, it is likewise possible to employ a gas sensor wherein a catalytically active cover layer is simply applied on the first sensor region as catalytic agent.

The invention is described below on the basis of further exemplary embodiments with reference to the schematic drawings. ~~Shown therein are:~~

Figure 1 a gas sensor of the present invention;

Figure 2 ~~the curve of resistance of~~ strontium titanate layers having different catalytic activation given varying lambda value; and

Figure 3 a sensor arrangement of the present invention.

According to Figure 1, a gas sensor 1 referenced overall as one comprises a carrier substrate ~~2~~ 2 on which a first sensor region 4 of strontium titanate is applied over a first, inherently known interdigital electrode structure 3 and on which a second strontium titanate sensor region 6 is arranged over a second interdigital electrode structure 5 spatially and electrically separated from the first strontium titanate sensor region 4.

The carrier substrate 2 is preferably manufactured of an electrically well-insulating, inert and heat-resistant material such as aluminum oxide and comprises temperature sensors, a heating arrangement and the like as needed and is known in and of itself (not shown).

The strontium titanate regions 4 and 6 are preferably applied in thick-film technique, for instance with silk-screening processes, as a result whereof they are porous. Both sensor regions 4 and 6 are initially identical in view of the layer

thickness and composition. In the first sensor region 4, however, traces of a catalytically active material such as titanium dioxide or platinum metal traces are introduced. The introduction of platinum metal traces can ensue in that a liquid solution of a platinum metal compound such as dissolved hexachloroplatinum acid is dribble onto the sensor region 4, dried according to a predetermined temperature profile and the residue is then subjected to thermolysis, so that platinum metal traces deposit in the entire layer.

In a practical exemplary embodiment, a gas sensor having strontium titanate sensor regions that was [sic] applied in thick-film technology by silk-screening is activated in the first sensor region with 80 µg platinum given a sensor region size ~~of 20 µm thickness and 5 mm X 3 mm area~~. The 80 µg platinum ~~were~~ introduced in the form of a 26% hexachloroplatinum acid solution.

The sensor region 6 is preferably free of such a catalytic activation. In this case, the catalytic agent comprises only the catalytically active substance in the first sensor region 4. Optionally, the second sensor region 6 can likewise be provided with catalytic activation whose catalytic activity, however, is kept low by introduction of a smaller quantity of catalytically active substance. This effects a pre-aging of the sensor: by reaction of exhaust gas constituents with the layer material, catalytically active substances can form therein little by little, which would gradually modify the response behavior of a non-activated layer; the slight activation anticipates this without disturbing the inventive effect.

According to Figure 2, a respectively clear, different resistance curve dependent on the lambda value is produced by the different catalytic activation in the two layers.

According to Figure 2, the resistance characteristic (shown dotted) of a strontium titanate sensor region that is already highly activated with 80 µg platinum onto the aforementioned volume drops monotonously with decreasing lambda in the rich below $\lambda<1$, whereas it is practically constant in the lean above the discontinuity region at $\lambda>1$. In contrast thereto, the resistance characteristic (shown with triangles and dots) of a sensor region without platinum activation exhibits a monotonous rise in the region of λ greater than 1.0, whereas its value of resistance changes practically not

at all in the rich below $\lambda<1$. The influence of only a slight catalytic activation is shown with reference to the example of a layer activated with 40 µg platinum on the indicated volume. The curve shown with broken lines still merely corresponds to the non-activated case in the lean above lambda equal to 1.

When the catalytically highly activated and the non-activated sensor region are connected parallel, the characteristic shown with a solid line in Figure 2 derives as parallel evaluation signal. For the evaluation of the permanently parallel-circuited arrangement, the sensor regions can be connected to a corresponding resistance measuring means. The changes in the parallel evaluation, i.e. the slope of the overall signal in the rich, practically correspond to the slope that is acquired with the sensor region 4 having catalytically highly active catalytic agent, whereas the slope of the overall signal in the lean mixing range approximately follows the curve like that covered in the sensor region 6 without catalytic activation. At the same time, the parallel evaluation signal exhibits a clearly pronounced discontinuity at $\lambda=1$, i.e. has a great signal boost.

The parallel circuit thus yields a monotonously changing resistance characteristic from which the size of a deviation from the rate value $\lambda=1$ can also be identified given a varying lambda value.

Particularly when the resistance values of the layers given variation of the lambda value do not cover approximately the same resistance range, an evaluation circuit as employed in Figure 3 can further be employed for evaluation.

According to Figure 3, the resistance of the first sensor region 4 acquired via the interdigital electrode structure 3 is supplied to a resistance measuring unit 7, to a digitalization unit 8 having an analog-to-digital converter, and is then applied in digitalized form to a first input 9 of a micro-processor 10. Correspondingly, the resistance acquired via the interdigital electrode structure 5 in the second sensor region 6 is supplied to a resistance measuring unit 11 and to an analog-to-digital converter 12 whose output signal is supplied into a second input 13 of the microprocessor 10. The resistance measuring units 7 and 11 are respectively optimally designed and adapted for the measurement of the different resistance ranges of the two sensor regions.

The microprocessor 10 is programmed such that it offers a signal at its output 14 that - below a predetermined lambda value - is only dependent on the resistance of the sensor region 4 at which the catalytic agent exhibits a high catalytic activity due to the greater quantity of platinum metal traces in the sensor region. The microprocessor 10 also outputs an output signal at its output 14 in the range of lambda greater than 1 that is exclusively dependent on the resistance value at the sensor region 6 as signaled to the microprocessor 10 at the signal input 13. The signal offered at the output 14 of the microprocessor 10 can be employed for regulating the air and/or fuel delivery.

The gas sensor arrangement of the present invention is operated in the following way:

After the installation of the gas sensor arrangement in an exhaust gas channel and connection of the gas sensor to external wiring as required, particular connection of its heating structure to a voted source, its temperature sensor to a temperature measuring arrangement and wiring of the electrodes 3 and 5 to the resistance measuring unit 7 or, respectively, 11, the motor is started. During operation, for instance while the motor warms up after a cold start or given load changes, the air/fuel mixture supplied to the motor changes in terms of its composition.

For example, a change from rich to lean thereby occurs.

With a logical comparison circuit, the microprocessor 10 initially detects that the signal adjacent at its input 9 indicates a low resistance of the sensor region 4; the motor is thus being operated in the rich below the discontinuity value. In this lambda region, only the resistance characteristic of the first sensor region 4, which is provided with catalytically active platinum metal traces, exhibits a noticeable slope, in contrast whereto the resistance characteristic of the sensor region 5 proceeds largely flatly. The microprocessor 10 decides with reference to the resistance value of the characteristic measured at the region 4 that the signal obtained at the signal input 9 is applied to the output 14 as overall output signal of the gas sensor.

When the lambda range wherein the motor is operated then changes, the resistance of the sensor region 4 increases until it suddenly changes in the region of

the point lambda equal to 1.0. A rise of the resistance value above a threshold lying in the discontinuity region is thereby identified in the microprocessor 10, it thus being certain that the fuel mixture being supplied to the motor is too lean. In response to the discontinuity in resistance, the microprocessor 10 outputs the signal detected at the input 13 and corresponding to the resistance of the sensor region 6 as output signal 14. A quantitative statement is derived from this signal in a following control regarding the extent by which the fuel mixture is too lean. Optionally, a signal processing can also ensue in the microprocessor 10, for instance in order to immediately obtain a statement about the lambda value and/or a required readjustment from the resistance value.

When the motor is again regulated back into the lean range or proceeds there into due to a load change, this is detected at the microprocessor 10 on the basis of the signal deriving from the sensor region 6 that suddenly changes given lambda equals 1, and the signal corresponding to the resistance of the sensor region 4 is again through-connected to the output 14. Switching is preferably carried out with historesis in order to suppress a tendency to hunt.

In this way, the evaluation system for two sensors is always operated on the respective branch of the respective lambda characteristic at which an especially pronounced change can be measured.

Whereas the present specification is directed to a sensor in thick-film technology, the inventive method can also be implemented for employment of a gas sensor with sensors that are provided with a catalytically active layer over at least one sensor region.

It is also possible to replace a logic circuit 10 that always forwards only the signal either from the sensor region 4 or from the sensor region 6 with an arrangement that weights the signals of both sensor regions according to one or both momentary resistance values.

A structure with discrete components is also possible instead of a logic circuit with microprocessor.